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Catch of the Potato Psyllid *Bactericera Cockerelli* (Hemiptera: Triozidae) with Yellow Sticky Traps Covered with Mesh of Different Color and Size

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Abstract

Bactericera cockerelli is a key pest in potato fields throughout the Americas. Yellow sticky traps are widely used for monitoring *B. cockerelli* within fields and regions. However, these traps lack specificity, which reduces their effectiveness and longevity. Using a mesh to cover their surface is a simple and efficient alternative to improve this limitation. Nevertheless, mesh traits may influence their effectiveness and there are currently no studies examining this for *B. cockerelli*. Two outdoor experiments were performed to evaluate the capture of *B. cockerelli* using twelve mesh colors and three sizes. Unmeshed traps were used as control. Additionally, the cleanliness of the traps (nontarget organisms and debris) was also evaluated. The experiments showed that yellow and medium (2.6 mm^2 hexagon-shape grooves)/large (4.5 mm^2 diamond-shape grooves) meshes did not significantly reduce the number of *B. cockerelli* caught and increased the trap cleanliness. Two additional experiments validated these traits. This study provides new useful insights for monitoring *B. cockerelli* with yellow traps.

Keywords Trapping system · Monitoring · Distribution · Mesh covered traps · Tomato psyllid

Resumen

Bactericera cockerelli es una plaga clave en los campos de papa en toda América. Las trampas adhesivas amarillas se usan ampliamente para monitorear *B. cockerelli* dentro de campos y regiones. Sin embargo, estas trampas carecen de especificidad, lo que reduce su eficacia y vida útil. Utilizar una malla para cubrir su superficie es una alternativa sencilla y eficaz para mejorar esta limitante. Sin embargo, las características de la malla influyen en su efectividad y para *B. cockerelli* no existen estudios. Se realizaron dos experimentos a campo abierto para evaluar doce colores y tres tamaños de malla a *B. cockerelli*. Se usaron trampas sin malla como control. Además, también se evaluó la limpieza de las trampas (organismos no objetivo y desechos). Los experimentos mostraron que las mallas amarillas y medianas (ranuras en forma de hexágono de 2.6 mm^2)/grandes (ranuras en forma de diamante de 4.5 mm^2) no redujeron significativamente los insectos capturados y aumentaron la limpieza de las trampas. Dos experimentos adicionales validaron estas características. Este estudio proporciona nuevos conocimientos útiles para el monitoreo de *B. cockerelli* con trampas amarillas.

Introduction

The potato (*Solanum tuberosum* L.) is one of the most important farm crops cultivated in America (FAOSTAT 2023). The potato psyllid, *Bactericera cockerelli* (Sulc) (Hemiptera: Triozidae) is a key pest of this crop within the continent both by feeding directly on plants and indirectly as a vector of the phytopathogen gram-negative bacteria ‘*Candidatus*

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Liberibacter solanacearum' (CLso), the causal agent of the potato zebra chip disease (Secor et al. 2009; Lin et al. 2011). *Bactericera cockerelli* is native to North America and is widely distributed in the most relevant potato production zones in this region, Central America, and the Caribbean (Crosslin et al. 2012; Swisher et al. 2013; Melgoza-Villagómez et al. 2018;). Regarding South America, *B. cockerelli* and CLso were recently reported in potato fields in Ecuador (Carrillo-Castillo et al. 2019; Caicedo et al. 2020).

South America is the most relevant potato-productive region of the Americas with about 59.14% of the total area cultivated in the continent (FAOSTAT, 2023). Recent studies noted that over 90% of the potato production area of South America is suitable and optimal for *B. cockerelli* and CLSo (Wan et al. 2020; Suwandharathene et al. 2022). Therefore, any monitoring systems that opportunely detect this insect is highly valuable.

The use of yellow sticky traps is one of the most sensitive strategies to capture *B. cockerelli* adults (Al-Jabr and Cranshaw 2007; Yen et al. 2013) and this system has been widely adopted by growers to detect the presence and abundance of the insect within their crops (Walker et al. 2014; Hodge et al. 2019), and by institutions which deploy a massive number of traps to monitor entire growing areas (Walker et al. 2015; Djaman et al. 2019).

Despite their wide use, yellow sticky traps lack target organism specificity which leads to unwanted capture of beneficial organisms such as pollinators (e.g., flies, wasps, and bees), predators (e.g., ladybeetles and lacewings) (Bian et al. 2016; Shin et al. 2020) and debris. This leads to a reduction of the traps effectiveness and longevity, reducing the available area for attracting and capturing insects, and the unwanted capture makes counting more difficult and less accurate (Sétamou et al. 2019; Rubio-Aragón et al. 2022). Modern alternatives to analyze the specimens trapped on the sticky traps such as identification software are being developed, however, those systems are not yet complete and available (Böckmann et al. 2021) making alternatives immediately necessary.

The use of a mesh to cover the sticky surface of the traps is a simple, economical, and efficient alternative. The principle of this technique is to use a mesh as a sifter to reduce unwanted captures (Sétamou et al. 2019). Nevertheless, the mesh traits such as color and groove size have a direct effect on the capture of the target organism; the color of the mesh changes the perception of the insects to the traps and the size filters the captures, reducing the catch of larger organisms and debris (Sétamou et al. 2019; Rubio-Aragón et al. 2022). It has been reported that *B. cockerelli* has a strong response to the sticky traps and is susceptible to the contrast effect originated by the combination of two different colors (Taylor et al. 2014).

Currently, no studies have been conducted to assess the effect of covering yellow sticky traps with meshes of different colors and sizes to catch *B. cockerelli*. The goals of the current study were to evaluate the capture effect of 12 mesh colors (white, black, red, orange, purple, light blue, dark blue, crimson, pink, gray, light green, dark green and yellow) and three groove sizes [small (diamond shape with 0.5 mm^2), medium (hexagon shape with 2.6 mm^2) and large (diamond shape with 4.5 mm^2)] to *B. cockerellli*.

Materials and Methods

Study Description

The effectiveness of yellow sticky traps (200 mm x 125 mm) covered with different mesh colors and sizes to capture *B. cockerelli* was compared in a commercial pepper (*Capsicum* spp.) farm during January-February 2022 in Angostura, Sinaloa, Mexico (25°9'15"N, 109°54 '34"W). Crops were fruiting and a heavy infestation of *B. cockerelli* was present. Traps were installed at the plant canopy with a separation of 6.4 m among traps. No pesticide applications were performed during the assays.

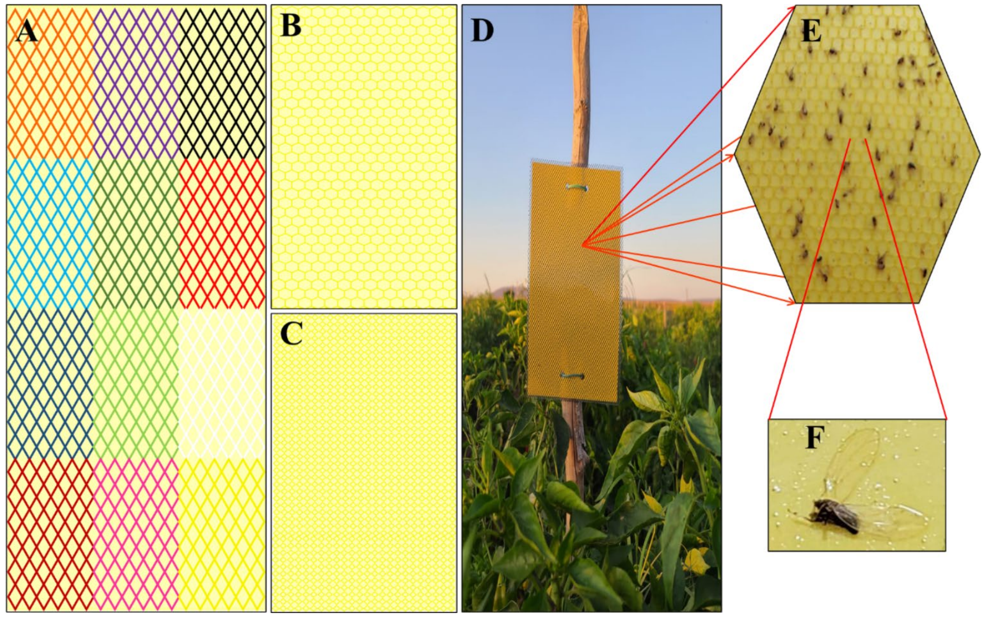
Manufacture of the Traps

The traps used in this study (20 × 12.5 cm) were made with yellow cardboard (CMYK, 0.00, 0.09, 0.76, 0.01) (58 × 89 cm) (250 g/m^2) (José Luis Mondragón y Compañia S.A. de C.V.), sealed with clear laminating film (polyethylene terephthalate [PET]) (3 mil [0.076 mm]) (Nuova), and coated with entomological adhesive (Imex-Adhesive). Only one side of the traps was selected to be glued and covered with tulle nylon mesh (Skytex México S.A. de C.V.) after it dried. The mesh was purchased in the cloth store "La Parisina" in Guamúchil, Sinaloa, Mexico. The mesh traits varied among experiments according to their goal.

Experimental Design

Each of the following assays performed in the current study was conducted as a completely randomized design with ten replications for treatment where each sticky trap was considered as a replication. Unmeshed traps were used as control. A magnifying glass (10X) was used to count the insects capture by the traps after the exposure period. The experimental design is illustrated in Fig. 1.

Fig. 1 The mesh covered yellow sticky traps field assays diagram. **A** = Diamond shape mesh of twelve colors measuring 3 mm long each diagonal **B** = Yellow hexagon shape with 1 mm long each side. **C** = Yellow diamond shape with 1 mm long each diagonal. **D** = Trap placement at the commercial fields. E = Covered trap after the exposure period. F = *Bactericera cockerelli* counting



Color Evaluation

Twelve different mesh (diamond shape with 3 mm long each diagonal) colors (orange [CMYK, 0.00, 0.73, 1.00, 0.00; manufacture code, 5810L61], purple [CMYK, 0.12, 0.65, 0.00, 0.69; manufacture code, 5810L83], black [CMYK, 0.00, 0.00, 0.00, 0.97; manufacture code, 5810L19], light blue [CMYK, 0.76, 0.14, 0.00, 0.00; manufacture code, 5810L21], dark green [CMYK, 0.77, 0.00, 0.96, 0.64; manufacture code, 5810L47], red [CMYK, 0.00, 1.00, 1.00, 0.00; manufacture code, 5810L36], dark blue [CMYK, 0.62, 0.56, 0.00, 0.58; manufacture code, 5810L27], light green [CMYK, 0.45, 0.00, 0.45, 0.00; manufacture code, 5810L46], white [CMYK, 0.00, 0.00, 0.00, 0.00; manufacture code, 5810L01], crimson [CMYK, 0.00, 0.89, 0.81, 0.42; manufacture code, 5810L37], pink [CMYK, 0.00, 0.27, 0.10, 0.00; manufacture code, 5810L50] and yellow [CMYK, 0.00, 0.03, 0.98, 0.00; manufacture code, 5810L72]) (Skytex México S.A. de C.V.) were used to evaluate the mesh color effect on the capturing of *B. cockerelli* (Fig. 1A). Traps were placed on an Anaheim (*C. annuum*) plot for 10 days. After the period, traps were removed from the crop and insects were counted.

Size Evaluation

Three different mesh sizes (large [diamond shape measuring 3 mm long each diagonal and 4.5 mm^2, manufacture code 5810L72, Fig. 1A], medium [hexagon shape with 1 mm long each and 2.6 mm^2, manufacture code 5820L72, Fig. 1B] and small [diamond shape measuring 1 mm long each diagonal and 0.5 mm^2, manufacture code 5833L72, Fig. 1C]) (Skytex México S.A. de C.V.) were used to evaluate the effect of the mesh size on capturing *B. cockerelli* and trap cleanliness. Traps were placed on an Anaheim plot for 10 days. After the period, traps were removed from the crop, insects were counted, and the cleanliness was estimated using the visual rating 1–9 scale described by Rubio-Aragón et al. (2022), with 1 indicating very clean trap and 9 very dirty trap full of nontarget organisms and debris (Table 1).

Table 1 Visual scale reported by Rubio-Aragón et al. (2022) to evaluate the sticky traps cleanliness

Level	Description
1	Sticky trap with 0–20% of its area covered with nontarget organisms and/or debris.
3	Sticky trap with 20–40% of its area covered with nontarget organisms and/or debris.
5	Sticky trap with 40–60% of its area covered with nontarget organisms and/or debris.
7	Sticky trap with 60–80% of its area covered with nontarget organisms and/or debris.
9	Sticky trap with 80–100% of its area covered with nontarget organisms and/or debris.

Corroboration Assays

To corroborate the effect of the mesh-covered yellow sticky traps on the capturing of *B. cockerelli* and its cleanliness, yellow sticky traps with the yellow-medium mesh (hexagon shape with 1 mm long each side and 2.6 mm^2, manufacture code 5820L72) were used in two additional assays.

The first assay was carried out in three different pepper typologies (Caribe [*C. annuum*], Habanero [*C. chinense*] and Serrano [*C. annuum*]) to evaluate the meshed traps in different crops and densities of the insect. The assay duration was 10 days and after that period the insects were counted, and the cleanliness was estimated using the rating scale described before.

The second assay was conducted in the Anaheim plot with a duration of thirty-days to evaluate the mesh-covered traps over a longer period, with the number of insects and cleanliness score recorded every ten days, leading to three total counts. Traps were randomly placed after each count.

Data Analysis

Data generated from the assays were subjected to Kolmogorov-Smirnov and Levene tests to verify the statistical assumptions of normality and homogeneity of variances, respectively. Nevertheless, the data did not comply with these assumptions, therefore, a nonparametric analysis of variances (Kruskal-Wallis and Dunn median tests with Bonferroni correction to separate treatments) was carried out with the mesh colors and sizes data ($p \leq 0.05$). For the validation trials, the Mann-Whitney *U* test was used to compare covered traps with uncovered ones. The calculations were performed with SPSS version 26.

Results

Effect of the Mesh Color on *B. Cockerelli*

The number of *B. cockerelli* adults caught on the covered sticky traps varied among the 12 mesh colors evaluated in comparison to the control (unmeshed traps) ($H = 48.460$, $df = 12$, $p < 0.001$) 10 days after traps installation (Fig. 2). Yellow was the only statistically similar mesh color to the uncovered traps with an average of 72.1 and 74.6 adults caught per trap, respectively, the capture of the remaining colors ranged from 24.38 to 46.88 (Fig. 2). The yellow color was selected for posterior evaluations.

Effect of the Mesh Size on *B. Cockerelli* and Traps Cleanliness

The number of *B. cockerelli* adults caught ($H = 25.44$, $df = 3$, $p < 0.001$) and cleanliness of the traps score ($H = 53.16$, $df = 3$, $p < 0.001$) to the covered sticky traps varied among the three mesh sizes evaluated in comparison to the unmeshed ones 10 days after trap installation (Fig. 3). The small mesh was the only size that differed significantly in the number of insects captured in comparison with the control traps with 35.05 and 69.90, respectively, the medium size had 60.86, and the large mesh 64.05 (Fig. 3A). Regarding cleanliness, the three sizes differed significantly from the unmeshed traps, the small mesh had the statistical lowest score according with the visual scale followed by the medium and large sizes with 2.64, 3.76 and 4.43, respectively (Fig. 3B). The control traps averaged 7.47. The medium size was selected for posterior evaluations.

Effect of the Yellow-Medium Mesh on *B. Cockerelli* and Traps Cleanliness

To validate the effect of the mesh color and size selected in the previous trials on the capture of *B. cockerelli* and the cleanliness of the traps, six comparative evaluations between yellow sticky traps covered with a yellow-medium

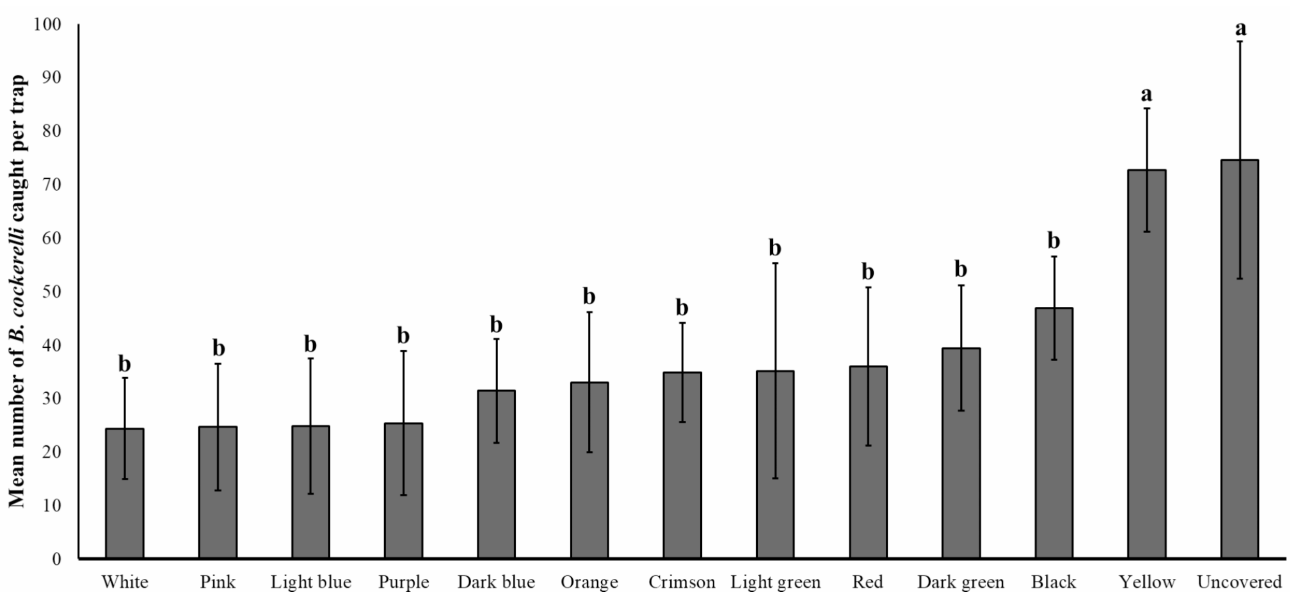


Fig. 2 Response of yellow sticky traps covered with 12 selected mesh colors plus unmeshed traps to *Bactericera cockerelli* (Mean ± SD). Means with different letters indicate significant difference according to the Dunn median test ($p < 0.001$)

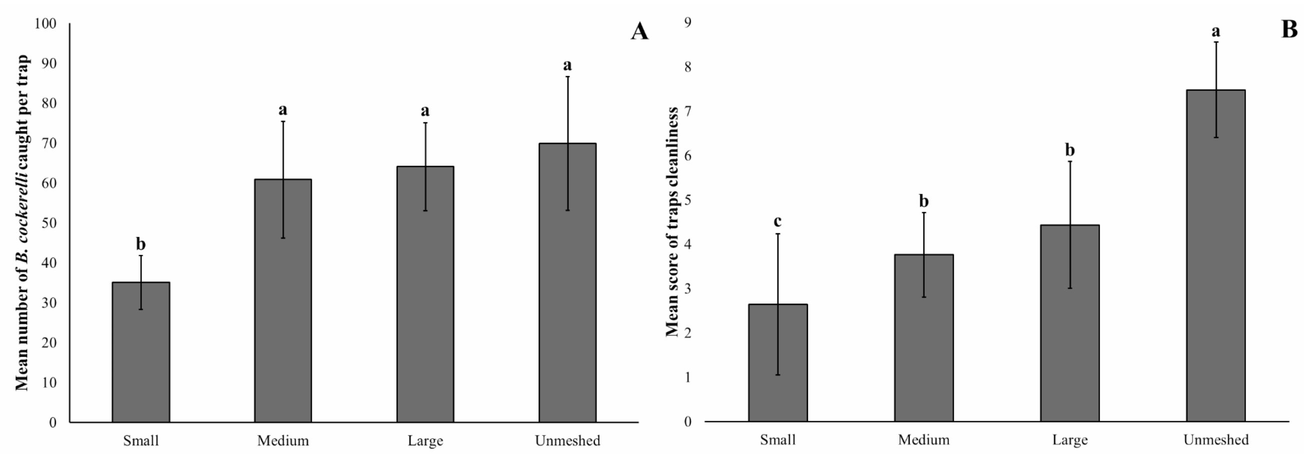


Fig. 3 Response of yellow sticky traps covered with three selected mesh sizes plus unmeshed traps to *Bactericera cockerelli* (Mean ± SD) **(A)** and cleanliness of the traps (visual scale 1–9) (Mean ± SD) **(B)**. Means with different letters indicate significant difference according to the Dunn median test (p < 0.001)

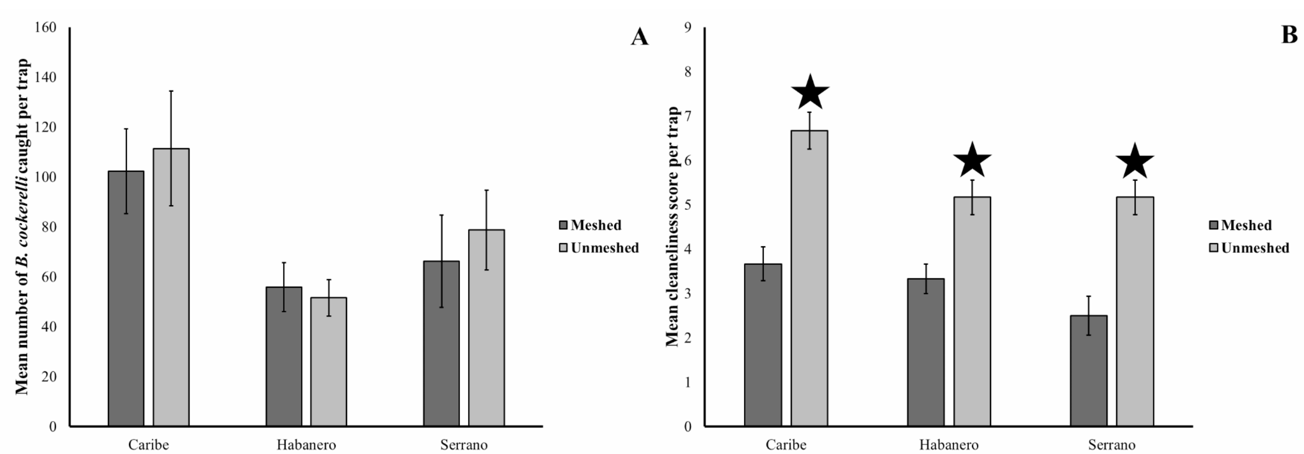


Fig. 4 Response of yellow sticky traps covered with the yellow-medium mesh versus the unmeshed traps to *Bactericera cockerelli* (Mean ± SD) **(A)** and cleanliness of the traps (visual scale 1–9) (Mean ± SD) **(B)** in three crops. Stars indicate a significant difference among treatments according to the Mann-Whitney *U* test (p ≤ 0.05)

mesh versus unmeshed traps were carried out in two different trials.

The first three evaluations were performed in different pepper plots (Caribe, Habanero and Serrano) 10 days after trap installation. There was no statistical difference in the number of *B. cockerelli* caught among meshed and unmeshed traps in either of the three pepper typologies (Caribe [H = 0.70, df = 1, p = 0.403], Habanero [H = 1.27, df = 1, p = 0.260] and Serrano [H = 2.25, df = 1, p = 0.133]) (Fig. 4A). On the other hand, the cleanliness of the traps score exhibited a significant difference in the three plots (Caribe [H = 12.81, df = 1, p < 0.001], Habanero [H = 7.52, df = 1, p = 0.006] and Serrano [H = 10.45, df = 1, p < 0.001]) (Fig. 4B).

The last three evaluations were carried out at intervals of 10 days after the installation of the traps. The number of *B. cockerelli* caught was significantly higher in the meshed traps after the second evaluation (first evaluation [H = 0.27, df = 1, p = 0.603], second evaluation [H = 4.20, df = 1, p = 0.040] and third evaluation [H = 12.24, df = 1, p < 0.001]) (Table 2). In contrast, the score of the cleanliness of the traps was statically lower in the meshed traps for all three evaluations (first evaluation [H = 5.07, df = 1, p = 0.024], second evaluation [H = 9.19, df = 1, p = 0.002] and third evaluation [H = 14.96, df = 1, p < 0.001]) (Table 2).

Discussion

Trapping protocols using yellow sticky traps are the most common and widely adopting monitoring system used by farmers and institutions to detect *Bactericera cockerelli* within crops and regions (Walker et al. 2014, 2015; Hodge et al. 2019: Djaman et al. 2019), therefore, any side effect of

Table 2 Response of yellow sticky traps covered with the yellow-medium mesh versus the uncovered traps *Bactericera cockerelli* (Mean ± SD) and cleanliness of the traps (visual scale 1–9) (Mean ± SD) for 30 days

	10 days		p	20 days		p	30 days		p
	Meshed	Unmeshed		Meshed	Unmeshed		Meshed	Unmeshed	
B. cockerelli	68.2 ± 6.4	71.7 ± 7.5	0.603	118.8 ± 16.7	96.0 ± 11.1	0.040	166.3 ± 16.2	128.6 ± 15.0	< 0.001
Cleanliness	2.0 ± 1.0	3.3 ± 1.2	0.038	3.5 ± 0.9	5.3 ± 1.2	0.002	4.7 ± 1.4	8.2 ± 1.0	< 0.001

Treatments with p ≤ 0.05 were significantly different according to the Mann-Whitney *U* test

these is a major concern. The lack of specificity exhibited by the sticky traps allows the capture of nontarget organisms and the collection of debris which reduce their effectiveness and life span; covering the sticky traps with a mesh significantly improves their specificity (Sétamou et al. 2019; Rubio-Aragón et al. 2022). However, the mesh traits such as color and groove size directly influence the capture of the insects and so far, there are no previous studies designed to assess these traits on the capture of *B. cockerelli*.

Out of the 12 different mesh colors evaluated, only the yellow mesh had a similar statistical number of insects caught as the unmeshed traps. When a mesh covers a sticky trap it changes the perception of insects to it, therefore, using a similar color of the mesh as the trap reduces that change to a minimum. *Bactericera cockerelli* is an insect with a strong visual reaction and it has been shows that it exhibits a susceptibility to contrasts between colors (Taylor et al. 2014). A similar result is reported by Sétamou et al. (2019) and Rubio-Aragón et al. (2022) who reported that a different mesh color than the trap significantly decreases the number of insects caught by the mesh-covered sticky traps. Therefore, using the same mesh color as the traps is highly recommended to reduce to a minimum the change in the perception of the insects to the covered traps.

Regarding the mesh groove sizes, out of the three sizes evaluated, the medium and large meshes caught similar insects as the uncovered traps. The main function of the mesh is to act as a filter for larger organisms and debris. The small mesh had diamond grooves of 1 mm long and a total area of 0.5 mm^2; meanwhile, the medium and large meshes had a hexagon shape of 1 mm long on each side and a total area of 2.6 mm^2, and a diamond shape of 3 mm long on each diagonal and a total area 4.5 mm^2, respectively. *Bactericera cockerelli* is a soft body insect with 1.5-2.0 mm length and 0.5 mm width (Liu and Trumble 2007; Vargas-Madríz et al. 2013) and although is not necessary for the entire body to get glued in the traps (Sétamou et al. 2019), the area of the small grooves mesh is approximately half the size of the insect. Therefore, the effectiveness of the mesh size is related to the insect body size; for instance, for *B. tabaci* there was no significant difference among these three mesh sizes because its size is approximately half the size of *B. cockerelli* (Rubio-Aragón et al. 2022). This same principle of the larger the mesh grooves, the larger the organisms and debris which are captured explains why the cleanliness of the traps significantly decreases in the medium and large meshes in comparison with the small mesh and why the three meshes differed statistically from the unmeshed control. Nevertheless, the type and number of organisms and debris involved in the trap placement site is a fundamental factor that affects the cleanliness of the traps. In the study carried out by Rubio-Aragón et al. (2022), the small and medium mesh did not differ significantly from each other like they did in our study. Therefore, we recommend using the mesh with the smallest size that does not statistically differ from the uncovered traps in the number of the targeted insects captured.

The effectiveness of the yellow-medium meshed traps showed consistency regardless of the host crop, the insect density, and the nontarget organisms and debris involved in the three pepper plots used to corroborate the effectiveness of the mesh traits previously selected. The number of *B. cockerelli* did not change significantly among meshed and unmeshed traps in either plot but the cleanliness score of the traps did in every crop, exhibiting a statistical lower score in the meshed traps. These results agree with Sétamou et al. (2019) and Rubio-Aragón et al. (2022) who described an independence of the meshed traps effectiveness with factors such as host crop, the target pest density, the unwanted organisms and debris abundance, and the season.

In the long-term trial with three consecutive counts of ten days each, the meshed traps had a significant higher number of *B. cockerelli* caught for the second and third evaluation and a significant lower score for the cleanliness of the traps for each evaluation in comparison with the unmeshed ones. Covering the sticky traps with a mesh creates a sifter effect that reduces unwanted captures (Sétamou et al. 2019) and this effect contributes to keep the effective catching surface and the perception of *B. cockerelli* adults to the traps. A similar result was shown by Rubio-Aragón et al. (2022) to *B. tabaci* where the significant reduction of unwanted catches helped to maintain a larger effective sticky area in the trap and a higher attraction of the insects to the meshed traps in comparison with the unmeshed ones.

The significant improvement in the specificity of the meshed traps brings several important benefits to the sticky traps monitoring protocols to *B. cockerelli*. For instance, these traps can stay in the field for a longer time reducing the number of traps needed and the plastic waste and are easier to clean and reuse (Dreistadt et al. 1998). Additionally, the meshed traps improve installation/remotion manipulation, increase the accuracy on the detection and counting of the insects, and reduces the evaluation time. Also, the mesh helps ease the removal of specimens for later identification, and conserves nontarget organisms such as natural enemies. All these benefits can increase the adoption and profitability of these monitoring systems. Additionally, there is a rising interest to use sticky traps as a control strategy for mass-trapping insects, especially pathogen vectors and/or insects resistant to insecticides such as thrips and whiteflies (Lu et al. 2012; Mao et al. 2018; Van Tol et al. 2021). Since *B. cockerelli* is a vector and resistance incidences have been reported (Vega-Gutiérrez et al. 2008; Szczepaniec et al. 2019), the yellow sticky traps could be a potential control strategy for this insect and the extra benefits of mesh covering the traps could improve the success rate of this alternative. Moreover, the yellow sticky traps can be carried out in alonr or in combination with the use of natural enemies (Gu et al. 2008), however, sometimes these methods are not compatible since these organisms are attracted by the traps and are unintentionally caught; the use of meshed traps improves the compatibility of the yellow traps with large predators such as lacewings and ladybeetles (Sétamou et al. 2019; Rubio-Aragón et al. 2022). Regarding their use with natural enemies, future studies should examine the effect of meshed traps on parasitoids. Additionally, another study to evaluate the use of yellow sticky traps as a control strategy to *B. cockerelli* alone or combined with natural enemies should be considered before recommending as an efficient method.

In summary, the addition of a yellow mesh (hexagon shape groove of 1 mm long each size and 2.6 mm^2) to the sticky surface of the yellow traps mitigates the unwanted side effect of lacking specificity to debris and nontarget organisms while maintaining the effectiveness to capture *B. cockerelli* in a short time and increasing it in the long term. The proposed meshed traps can bring a substantial improvement to the diverse monitoring programs designed to constantly detect the distribution of *B. cockerelli* within fields and regions worldwide.

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Author Contributions All authors contributed to the study conception and design. Material preparation, field work and data collection by Walter Arturo Rubio-Aragón, Jorge Alberto Edeza-Urías, Juan Antonio Castro-Diego and Guillermo Gómez-González. Data analysis by Walter Arturo Rubio-Aragón and Carlos Alfonso López-Orona. The manuscript was written by Walter Arturo Rubio-Aragón, Jesús Enrique Retes-Manjarrez and Carlos Alfonso López-Orona. All authors commented, read, and approved the final manuscript.

Declarations

Conflict of interest Authors declare no conflict of interest.

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